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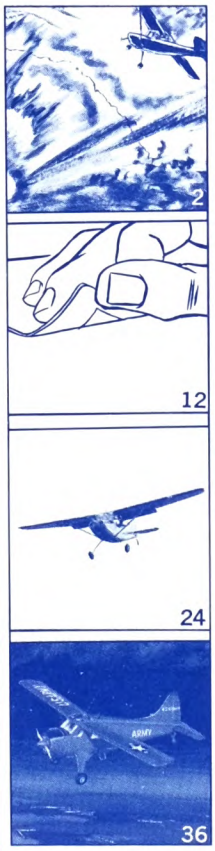

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ABOUT THE COVER

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The final stanza of John McCrae's "In Flanders Fields" reminds us on Independence Day that the torch of freedom has long been held aloft by a succession of courageous hands

The mission of the U. S. ARMY AVIATION DIGEST is to provide information of an operational or functional nature concerning safety and aircraft accident prevention, training, maintenance, operations, research and development, aviation medicine, and other related data.

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DEPOSITORY

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From USARV AVIATION PAMPHLET, April 1968

E. H. Flinn

Air Force Flight Dynamics Laboratory
Control Criteria Branch

Helicopter Rotorwash Effects

A NUMBER OF recent mishaps have been reported in which the rotorwash of helicopters was considered to be a possible factor. As a result of concern in this area, the Air Force Flight Dynamics Laboratory was requested by the USAF to study this problem area and provide information relative to the operation of fixed wing aircraft in the vicinity of helicopters.

Vortices which trail from the wing tips of any airplane in flight are quite powerful and can persist for several minutes after the passage of the aircraft (see fig. 1). The average velocity and the total energy of the rotorwash in the wake of a helicopter in forward flight are similar to those for an airplane of the same weight and span and flying at the same airspeed. At a distance of one to two rotor diameters downstream from the helicopter with forward speed, the vortices shed by the rotor tips roll up into a pair of vortex cores (fig. 2) which are similar to the vortices of conventional aircraft. In addition to the effects of rotorwash from a helicopter in forward flight, there are also problems associated with the downwash at or near hovering flight.

VORTEX SETTLING, SPREADING AND DECAY

Since each of the trailing vortices produces a downward movement, the vortices settle with time. If the vortices are generated more than a few rotor diameters above the ground, they tend to maintain a constant lateral spacing and have a constant downward velocity. As the vortices approach the ground to within two or three rotor diameters, their motion is slowed and they begin to spread apart laterally. When the vortices are generated closer to the ground, their initial vertical velocity is less. They tend to settle to a level somewhat closer to the ground and spread laterally at a faster rate than for the first case (fig. 3).

A wind of more than 5 knots, or convective action

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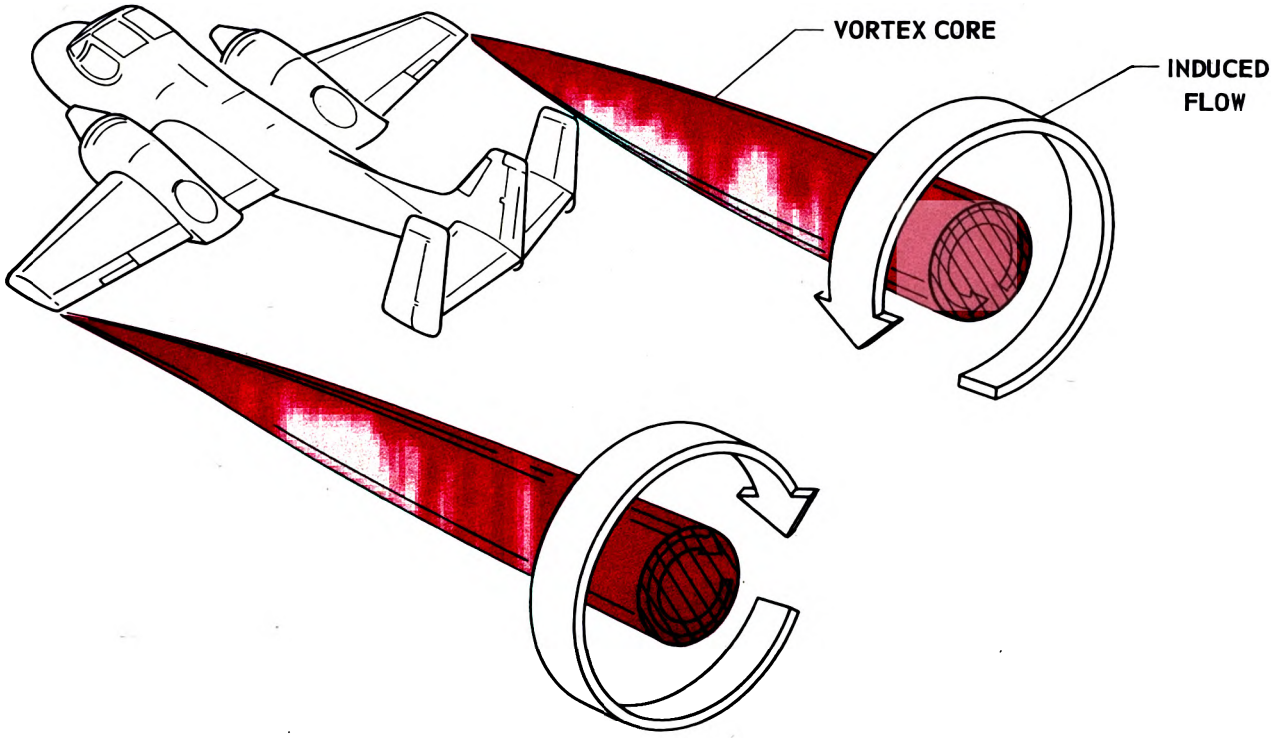

Figure 1. Illustration of trailing vortex wake behind a conventional aircraft.

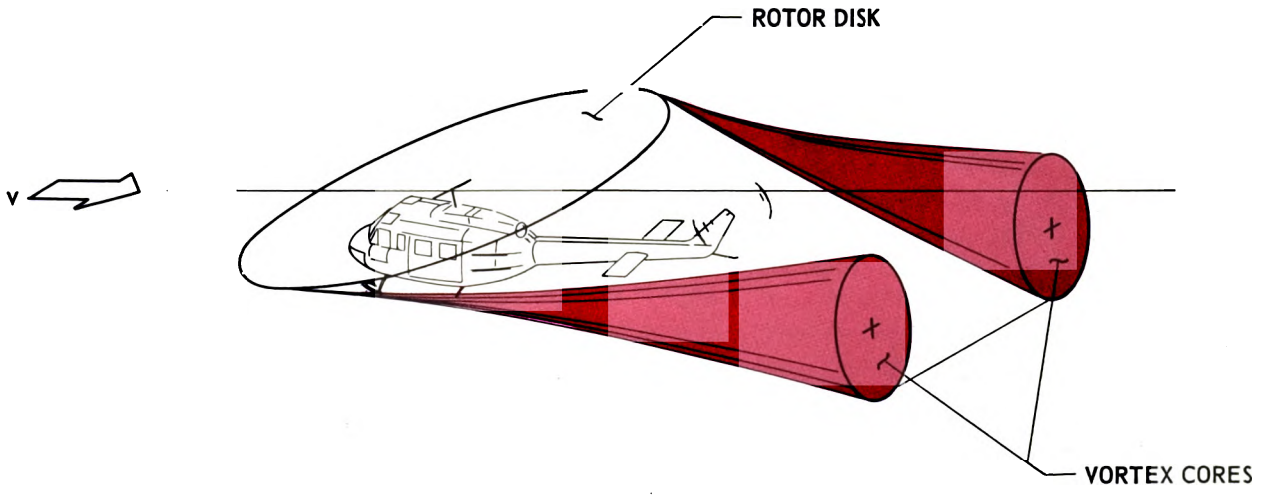

Figure 2. Illustration of the helicopter wake showing how the vortices roll up at the tips and expand downstream.

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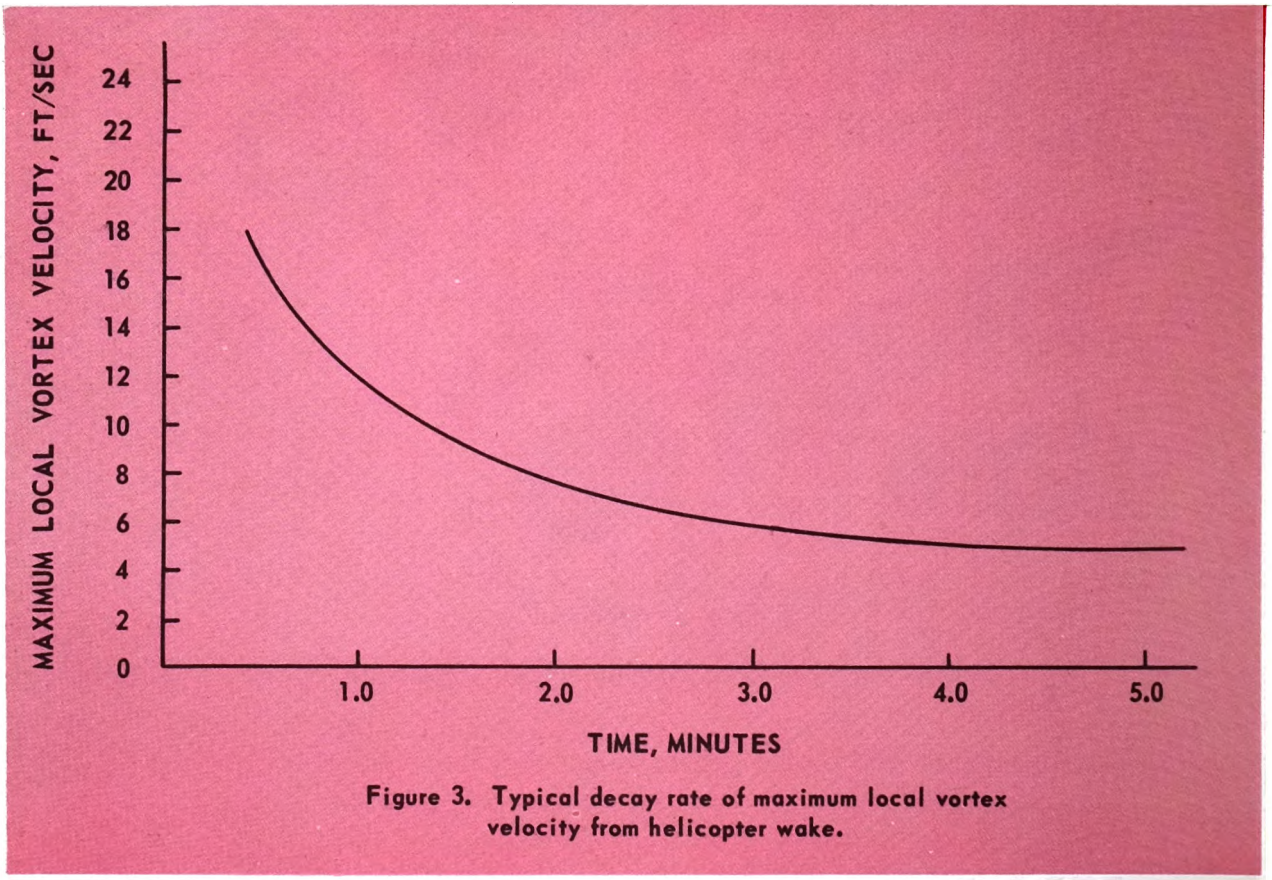

Figure 3. Typical decay rate of maximum local vortex velocity from helicopter wake.

due to heating, would be accompanied by atmospheric turbulence, particularly at the lower altitudes, which would tend to cause more rapid decay or complete disruption of vortices. Where the vortices are close to the ground, frictional forces between the ground and the vortex-induced airflow would contribute to vortex decay. Although pilots have reported apparent encounters with trailing vortices at separation times estimated at 5 minutes or more, no actual measurements of vortex intensities have been recorded for separation times greater than 3 minutes. The factors which determine the time of this final dissipation of the vortices, however, are not known.

EFFECTS ON AIRCRAFT PENETRATING TRAILING VORTICES IN FLIGHT

There are three modes of penetration of the trailing vortices of a helicopter which will have distinctly different effects on the penetrating aircraft. These modes are cross-track, along-track between vortices, and along-track through the vortex center.

The first mode of penetration, cross-track, would most likely occur during flight in a traffic pattern in the vicinity of an airport. This type of vortex encounter would tend to cause pitching and vertical motions and produce loads on the penetrating aircraft in a fashion similar to that of flight through gusts.

Vertical loads encountered in this mode will be a function of time and the ratio of gross weight of the penetrating aircraft to the helicopter generating the vortex. The instinctive control reaction by pilots to this type of disturbance in light aircraft could cause a substantial increase in loads, to the extent that the ultimate load could be exceeded. However, since the strength of the vortex is decreasing rapidly with time, little danger of structural damage to light aircraft would occur with separation times greater than 1 minute.

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Large aircraft have, in general, slower response to controls in contrast to light aircraft and would not experience much increase in load due to pilot reaction. Thus, the conditions under which this mode can be dangerous appear to be largely limited to the case of light planes crossing the wake of a larger aircraft within about a minute after the passage of the larger aircraft.

The second mode of penetration, along-track between vortices, would most likely occur during takeoff, climbout, landing approach, or formation flying. In this mode, a downward flow would act on the penetrating aircraft and cause it to settle, or at least reduce its rate of climb. This effect would diminish quite rapidly as the penetrating aircraft is forced below the plane of the vortices. However, at very low altitudes it could be very dangerous with the airplane striking the ground before a recovery could be made. A greater hazard in this case is the possibility of the pilot stalling the aircraft in an effort to check the settling tendency. This particular vortex effect can persist up to 2 minutes after passage of the generating helicopter.

As pointed out earlier, the vortices stop settling and begin to spread laterally near the ground. Winds can thus have a significant effect on the location of the vortex with respect to takeoff and landing situations. Headwinds move the vortices back toward the takeoff point. However, the lateral displacement tends to lessen the effects on a penetrating aircraft. Cross-

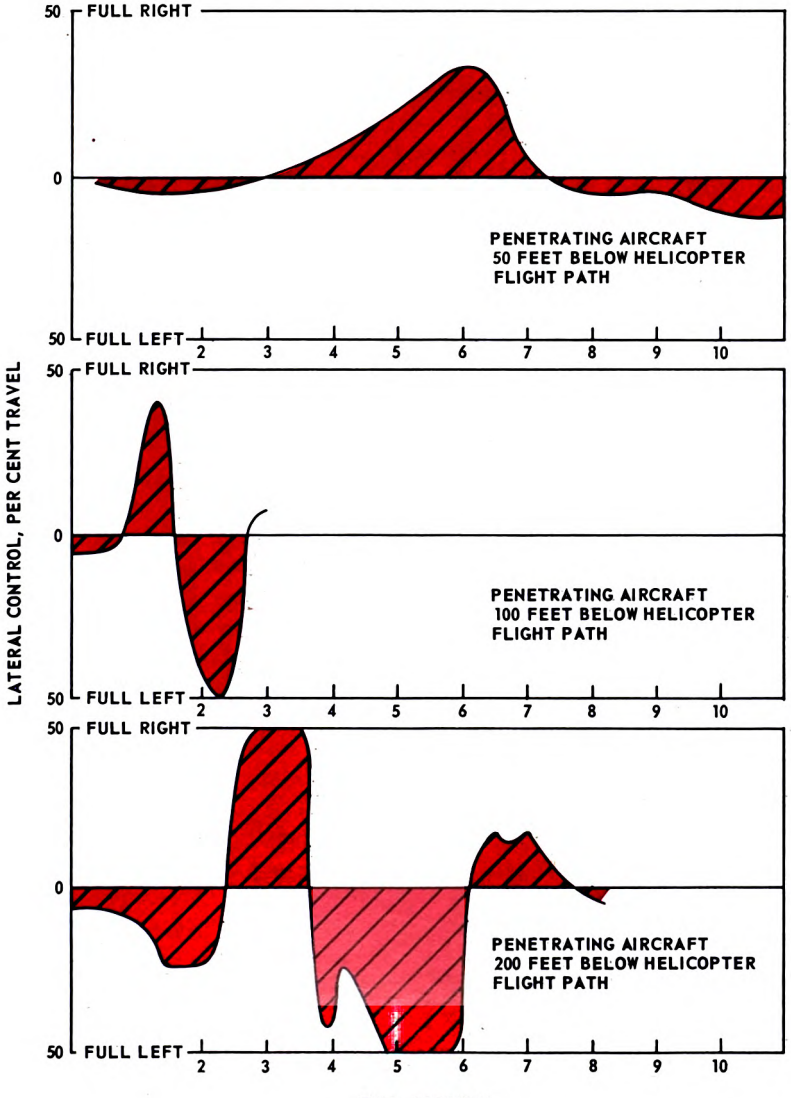

Figure 4. Pilot induced lateral control after initial penetration of helicopter vortex.

...the lateral upsets encountered would be very dangerous if they occurred near the ground...

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winds, especially if light, are generally considered to be most detrimental. If the crosswind speed is equal to the lateral speed of the vortex, this vortex can remain in a fixed position, above or on the runway, until it is dissipated, causing very serious takeoff and landing problems. In general, light crosswinds tend to increase vortex encounters close to the ground and decrease the chances of encounter at altitude.

The third mode of penetration, along-track through the vortex center, would most likely occur during takeoff, climbout, landing approach, or formation flying. This penetration mode is perhaps the most dangerous of the three modes. The penetrating aircraft would be subjected to a rotational flow which induces a rolling motion to the aircraft. The roll rate induced by the vortex is primarily dependent upon the vortex rotational velocity, time, and penetrating aircraft size. It is essentially independent of the speed of the penetrating aircraft. The rate of roll available from the penetrating aircraft's lateral controls, however, is proportional to speed. Thus, the degree of controllability of the penetrating aircraft will strongly depend upon the separation time between the generating aircraft and the penetrating aircraft, with the rolling decreasing quite rapidly with increasing separation time.

Substantial lateral upsets are indicated for this mode of penetration at separation times of less than 2 minutes, even for aircraft of equal weight. This could be very hazardous within 300 feet of the ground on a takeoff or landing, especially for light aircraft. Although the upset would tend to be smaller for a large and heavy penetrating aircraft, the extent of the upset that could be tolerated is also less because of its slower recovery time.

Figure 4 was extracted from a NASA report to graphically show the effects of penetrating the vortex wake behind a helicopter. During this test, a T-28 aircraft, having a nominal gross weight of 7,400 pounds and an airspeed of 80 knots, was flown at various distances below the flight path and approximately 1,000 feet behind a CH-34 helicopter having a nominal gross weight of 6,900 pounds and an airspeed of 40 knots. Time histories of the pilot's control inputs required to prevent lateral upset during the penetration are shown for distances of 50, 100 and 200 feet below the helicopter's flight path. In the last case, the pilot was required to use about 90 percent of the total available lateral control in less than one-half a second to maintain nearly level flight. A control input of this magnitude in calm air at the flight test conditions would result in a rate of roll of approximately 36° per second.

During these same tests, a landing approach penetration was simulated by a descent at 250 feet per minute on course through the wake, at 1,000 feet behind the helicopter. As the airplane entered the wake, a moderate but pronounced rolling occurred and the rate of descent was increased to 500 feet per minute. In summarizing this test program, the research pilot who flew the T-28 commented that the lateral control limits of the airplane were slightly exceeded and that the lateral upsets encountered would be very dangerous if they had occurred near the ground.

In general, helicopter wakes are similar to wakes of fixed wing aircraft, and it follows that operational problems associated with wake encounters are similar. The lower operating speeds of helicopters, however, can result in higher intensity wakes and consequently more severe wake encounters. Although it has been shown that a rotor wake vortex encounter in flight can be a real hazard, such an encounter requires that the penetrating aircraft be in a certain limited spatial region at a certain time, under suitable atmospheric conditions. Such a combination of circumstances apparently occurs infrequently, despite the frequency of high density traffic in terminal areas.

Exposure to the rotor wake vortex hazard, particularly in takeoff and landing operations, can be substantially reduced by suitable air traffic control procedures which emphasize appropriate sequencing and spacing of flight paths. Basically, the penetrating aircraft should be on or above the flight path of the vortex generating aircraft or have a separation time of at least 1-1½ minutes, if below the flight path of the vortex generating aircraft. The lighter the weight of the penetrating aircraft with respect to the generating aircraft, the more serious is the hazard to be expected. However, as a caution note, the vortex intensity of the helicopter rotor wake is a direct function of disk loading. Thus, helicopters with greater disk loadings will produce wakes of greater intensity at a given speed, regardless of size, and larger helicopters with the same disk loadings produce wakes enlarged only in size. As one final note, pilots flying light observation aircraft should take precautions with extra care, particularly when low and slow.

Although this report has not presented any details regarding problems associated with hovering helicopters, a brief review of the literature concerning helicopter downwash research indicates the following precautions for this type of operation should be noted. In general, helicopters should not be hovered closer than 1,000 feet upwind of an active runway, or operated at high thrust under no-wind conditions closer than three rotor diameters to other aircraft.

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